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Discharge Areas – A Comparison between Three Regions in the Southern Baltic

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With 12 Figures and 5 Tables

Key words: Tideless estuaries, Baltic Sea, discharge area, eutrophication, sustainable development

Abstract

Tideless estuaries are very common on the western, southern and eastern Baltic coast. They play an important role as buffers and filters for the Baltic Proper. These functions can vary, depending on discharge areas and the situation in the estuaries themselves. Our knowledge of the estuaries varies widely, ranging from more or less simple descriptions to a fairly complete understanding of the processes taking place in their ecosystems. So far, only one preliminary comprehensive study has been performed for the whole area (Baltic Sea Environment Proceedings No. 40, HELCOM 1991).

Three different discharge areas connected to tideless estuaries are compared in some detail:
- the shallow polytrophic Darss-Zingst Bodden Chain, Germany
- the shallow eutrophic Puck Bay, Poland
- the deeper mesotrophic Gulf of Riga, Latvia.

Starting points are discharge areas, discriptions of the water bodies and main loads. The development of the ecosystems under the influence of anthropogenic impacts during the last 40 years is then described.

Conclusions are drawn concerning:
- the general behaviour of such systems
- the benefits and drawbacks of the discharge areas, the loads, and the structures and functions of the estuaries
- special problems regarding the buffer and filtering capacities of the systems in question
- economic consequences.

High variability and elasticity are the main characteristics of these tideless estuarine ecosystems. Multivalente economic utilization of these resources and functions is the best way to save such ecosystems and money as well.

Introduction

The southern and eastern Baltic coast is characterized by tideless estuaries. They are important filters and buffers for the Baltic Proper. However, during the last 40 years most of them have been overloaded by anthropogenic activities, mainly through high inputs of inorganic nutrients inducing eutrophication. Meanwhile, in some estuaries eutrophication is so extreme that they have not only lost there filter and buffer capacity, but have themselves become loading sources for the Baltic Sea.

We will compare 3 different estuary systems - the Darss-Zingst Bodden Chain (DZBC), the Puck Bay (PB) and the Gulf of Riga (GR) - to demonstrate the interaction between estuary type and discharge area and its consequences for the eutrophication of these ecosystems.

Two of the estuaries (DZBC, PB) are small and shallow (Table 1). The other (GR) is much larger and deeper. However, the discharge/surface area relations are almost identical. Agricultural activities in the discharge areas are also quite similar. PB and GR are more influenced by big cities (Gdansk, Riga). PB is connected to the Vistula discharge area through the Gulf of Gdansk. GR is more influenced by lowland rivers.

Table 1. Some characteristics of the estuaries.

	DZBC	PB	GR
Area (km^2)	200	100	16.330
Discharge Area (km^2)	1.600	875	134.000
A/DA	1:8	1:9	1:8
Volume (km^3)	0.4	0.3	424

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Results

Darss-Zingster Bodden Chain (DZBC)

This estuary consists of 4 larger water basins linked by more or less narrow channels (Fig. 1). The narrow and shallow outlet is in the northeastern part. This morphology has a significant influence on the exchange (up to 35 times a year in the eastern, 1–3 times in the western part of the system) and the trophic situation in the basins (east: mesotrophic/ eutrophic, west: poly-/hypertrophic).

The discharge basin contains only a few minor rivers. Non-point loading predominates (BEHRENDT & BACHOR 1996), but 2 small towns act as waste water point-sources for the bodden system. Green crop production and stockbreeding are the main agricultural activities. High loads from intensive agriculture for the past 25 years have led to increasing eutrophication. However, the loads have diminished greatly since the reunification of Germany owing to the dramatic decline of stockbreeding and creation of the National Park "Vorpommersche Boddenlandschaft". A larger sewage treatment plant besides Saaler Bodden has greatly reduced the municipal organic loads since 1989 too. Nevertheless, the whole ecosystem is still polytrophic. This is emphasized by average annual chlorophyll content of 70 $\mu g \times ml^{-1}$ in Barther Bodden.

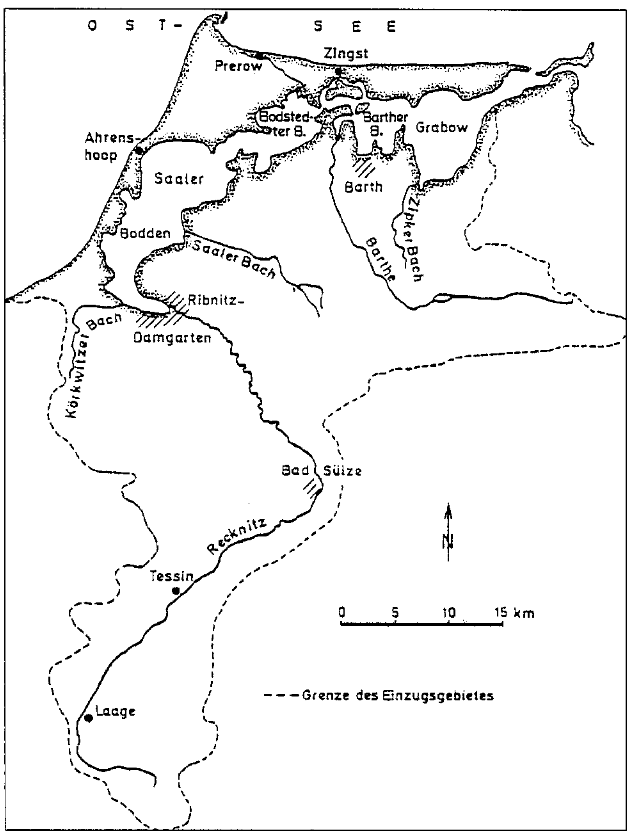

Fig. 1. The Darss-Zingst Bodden Chain (DZBC) and its catchment area.

Table 2. Selected characteristics of the Darss-Zingst Estuary.

- Highly productive shallow water estuary
- Increase in thophic level by nutrient loads is more pronounced than in other ecosystesms
- Ecosystem fluctuations controlled mainly by physical factors
- Irregular exchange processes with the Baltic Sea, dominated by outflow ("washout effect")
- Dominance of species with tolerance to high environmental variability
- Historically young ecosystem. Invasion of new species is easily possible
- Multivalent use of this ecosystem is a suitable way to reduce the antagonism between ecology and economics

Characteristic features and overall conclusions from our results (e.g. SCHIEWER 1990, 1994) describing such a system are given in Table 2.

Remarkable changes took place in Barther Bodden from 1981 to 1992. In 1981 a sudden decline in submerse macrophytes took place and led to the dominance of phytoplankton (SCHIEWER 1998a). The consequences were

- the phytoplankton community shifted to nano- and picoplankton dominance which induced a change from nutrient (mainly N) to light limitation. Small green algae and small cyanobacteria are the most important groups. No loss of species was detected.
- in the past few years the zooplankton has also changed owing to a decrease in *Eurytemora affinis* and larger rotifers and an increase in protozooplankton and small rotifers such as *Synchaeta*.

These structural changes were reflected in the system functions:

- microbial food webs dominate (Fig. 2). More than 90% of the planktonic carbon turnover is mediated in this way SCHIEWER & JOST 1991; SCHIEWER 1998b).
- increasing turnover rates in the pelagic zone
- high respiration rates leading to the respiration of large amounts of organic material
- increase in the remineralization rates of nitrogen and phosphorus (Fig. 3). This led to a self-eutrophication of the system.

Such an ecosystem is very stable both against further eutrophication and restoration. A atmospheric fall-out might be able to compensate the nutrient losses by exchange with the Baltic Sea and by denitrification in the system itself.

The eutrophication took place in steps in the DZBC (Fig. 4). The main steps were characterized by losses of diatom dominance, followed by the decline of submersal macrophytes, increases in green algae followed by a shift to smaller green algae and cyanobacteria and to the dominance of

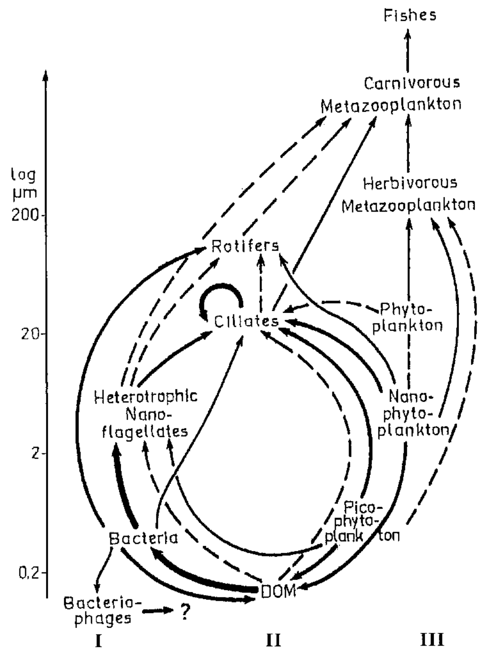

Fig. 2. Microbial food web. DZBC, late spring/early summer situation. I = side chain through bacteriophages (proven abundances of virus sized particles: $10^8 \times ml^{-1}$). II = microbial food web. Main pathway for carbon turnover, mainly by pico- and nanoplankton. Internal loop in the ciliate community (arrow). III = "classical" pelagic food web. The typical components are net plankton and fishes. Minor role only. DOM = Dissolved Organic Matter.

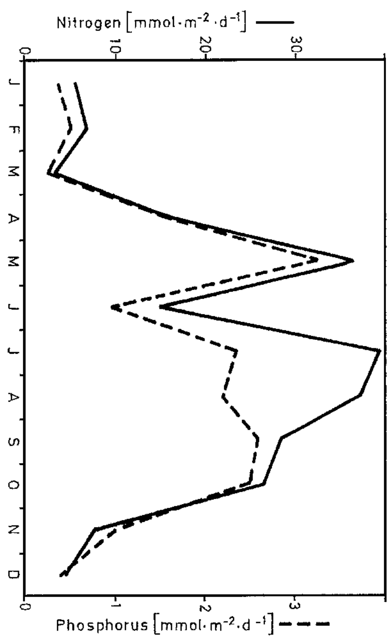

Fig. 3. Nitrogen and phosphorus remineralization rates. Monthly means calculated from the respiration of pelagic phagotrophic consumers using the REDFIELD ratio 106:16:1 for C:N:P for phytoplankton.

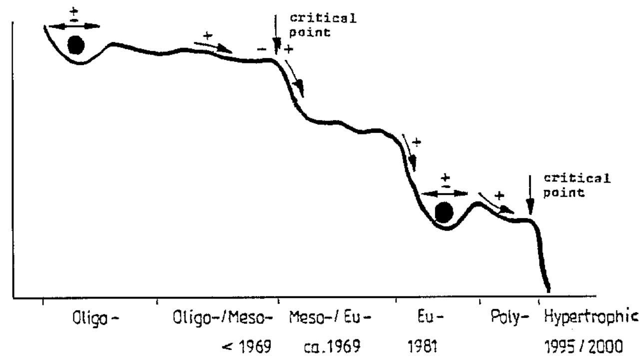

Fig. 4. Hypothetical eutrophication model of the Barther Bodden, DZBC (SCHIEWER 1994).

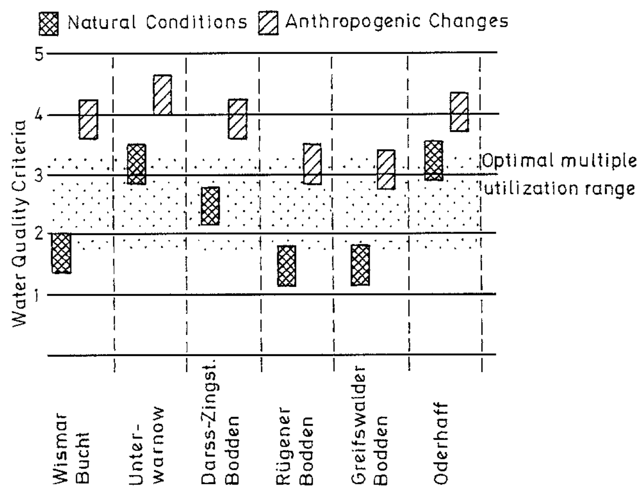

Fig. 5. Water Quality of different German coastal waters (SCHLUNGBAUM et al. 1994).

protozooplankton and small rotifers. Reduced loads and the high activity of the new planktonic community will stabilize the ecosystem in its eutrophic/polytrophic state during the next years. The same forecast also applies to the other German Boddens, which are more or less at the same eutrophic level (Fig. 5).

Puck Bay (PB)

The PB (Fig. 6A) is in the upper western part of the Gulf of Gdansk. The inner part is partly isolated by a sandy bar (Fig. 6 B).

PB and its discharge area are relatively small. Pure soils mainly used as meadows and for pasture and green crop production and a population of only 60.000 inhabitants have left PB more or less unchanged. But point sources from landfill sites, the small towns and villages in the area with its

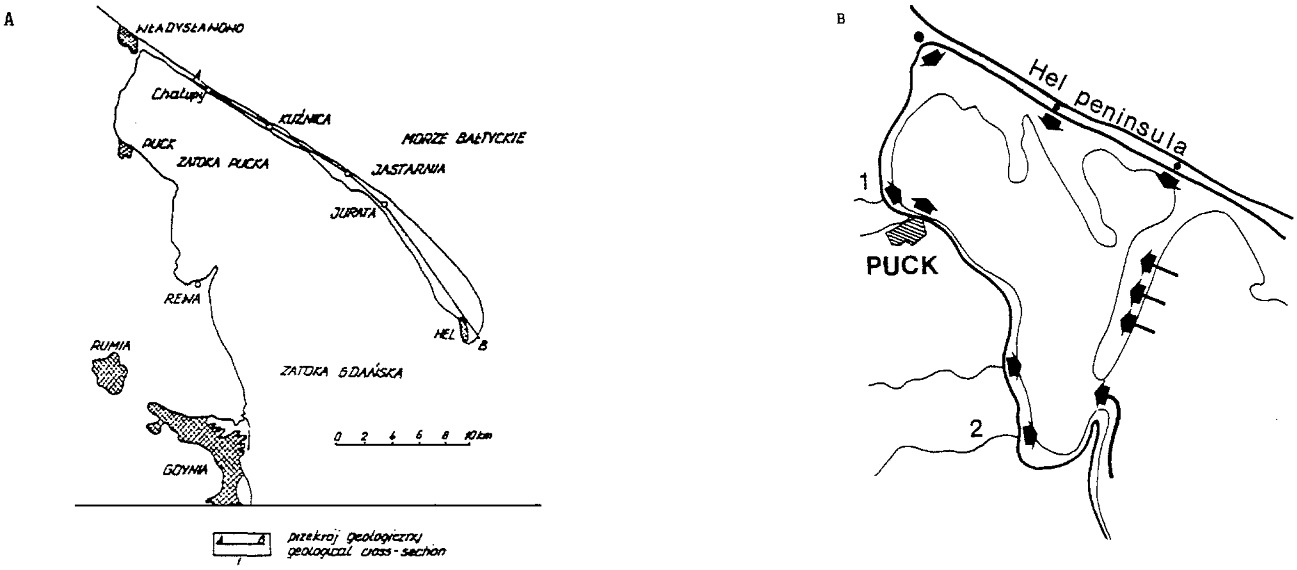

Fig. 6. Puck Bay. A) The whole Puck Bay in the Gulf of Gdansk (FRACZEK 1993). B) Main and secondary coastal sources of pollution of the Puck Bay (CISZEWSKI & STYCZYNSKA-JUREWICZ 1990). Short arrows: discharge from rivers and potential local contamination from coastal villages (black points); medium arrows: inflow of contaminated water masses above the sandy barrier from the outer Puck Bay (= western part of the Gulf of Gdansk proper): long arrow: main current of pollution from Mechelinki collecting pipe flowing through "Depka" collin. 2 m isobate marked with fine line. 1 – River Plunica; 2 – River Reda.

Table 3a. Tendencies of nutrient induced changes in the Puck Bay. Mean values of NO_3- and PO_4-concentrations (NOWACKI 1993), Chl a-concentrations (RENK 1993), average net phytoplankton abundance (WIKTOR & PLINSKI 1992; PLINSKI 1995) and mean biomass of benthic fauna (WOLOWICZ 1993).

	NO_3 (μmol · dm^{-3})	PO_4 (μmol · dm^{-3})	Chlorophyll a (mg · dm^{-3})	Phytoplankton abundance (10^3 · dm^{-3})	Biomass of benthic fauna (g FW · m^{-2})
1962	–	–	–	–	204
1970	–	–	2.5	–	–
1977	–	–	–	129	396
1080	–	–	4.5	–	–
1981	5.0	0.4	–	378	–
1986	6.5	1.2	–	–	–
1987	–	–	–	–	396
1988	7.0	1.8	–	–	–
1990	–	–	6.0	–	–
1992	9.2	1.9	–	–	–
1993	–	–	–	420	–

Table 3b. Nutrient induced changes in nearshore waters.

Increased nutrient concentration
Enhanced phytoplankton growth
Poor light conditions for submersal macrophytes
– Reduction in the growth depth for macroalgae
– Reduction in slow growing red and brown algae
– Losses of eel grass
– Increase in fast growing green and brown algae
Changes in benthic fauna
Changes in sediment structure

growing tourism in summer and the influences from Gdansk City led to increasing eutrophication (HERBICHOWA et al. 1993).

In 1988, a two-stage sewage treatment plant was built at Swarzewo near Puck. This has reduced the organic load by 80% and, consequently, the distribution of bacteria such as *Escherichia coli* in the PB. However, its outfall in PB itself and the concentrated input of inorganic nitrogen and phosphorus has negatively influenced the flora and fauna of the area. The higher nutrient content has enhanced phytoplankton growth to the detriment of submersal macrophytes (Table 3a, b).

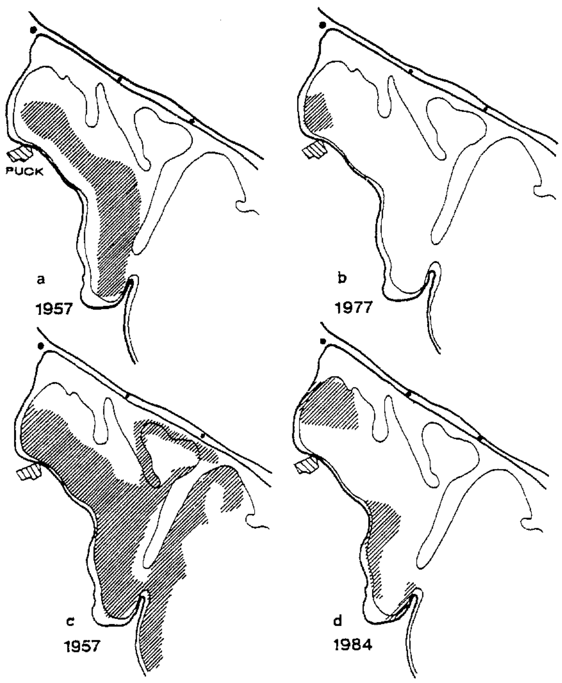

Fig. 7. Changes in the area covered with macrophytes in the Puck Bay (ZMUDZINSKI 1995). **a, b** – *Fucus vesiculosus*. a – in 1957, after CISZEWSKI (1962); b – in 1977, after PLINSKI (1982). Complete disappearance which occurred in 1979 was confirmed in 1987 monitoring, performed by the staff of the Institute for Environmental Protection. **c, d** – *Zostera marina*: c – in 1957, after CISZEWSKI (1962); d – in 1984, after PLINSKI (1986); in the 1987 monitoring a significant reduction was recorded by the staff of the Institute for Environmental Protection.

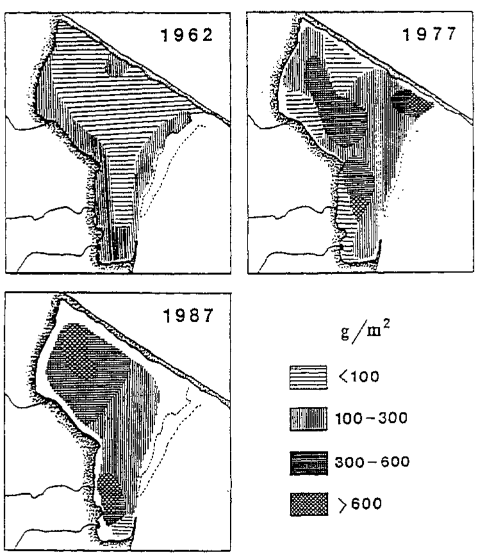

Fig. 8. Changes in biomass distribution (wet weight) of bottom macrofauna in the Puck Lagoon area (after ZMUDZINSKI 1962, LEGEZYNSKA et al. 1977, OSOWIECKI 1987).

Fucus vesiculosus, *Furcellaria fastigiata* and *Zostera marina* have been completely or almost completely lost (Fig. 7). This has affected the benthic fauna (Fig. 8) and, finally, the sediment structure.

Gulf of Riga (GR)

The Gulf of Riga (Fig. 9) is very different from the two other regions mentioned:

- much greater areas of the water body and catchment area
- more influenced by rivers
- depth down to 30 m with regular thermal stratification
- much more open to the Baltic Sea with an high water through-flow, mainly from west to northeast in cold season and from northeast to southwest in the warm season.

The total nitrogen (ca. 70.000 t $\times$ a^{-1}) and phosphorus inputs (ca. 3.000 t $\times$ a^{-1}) are mainly river-borne, while the BOD and heavy metals are dominated by sewage from Riga town (Fig. 10).

The thermal stratification influences the oxygen concentration. In the hypolimnion it can be as low as 3 mg $\times$ l^{-1}.

The northern geographic position of the GR is important. It yields low average temperatures and long winter periods

Table 4. Macrozoobenthos.

Normal situation:
Poverty in species composition
Typical taxa ranged by biomass:
Molluscs (e.g. *Macoma baltica*, *Mytilus edulis)*
Snails (e.g. Gastropoda; *Lymnea peregra)*
Crustaceans (e.g. *Pontoporeia fermorata*, Gammaridae)
Polychaeta (e.g. *Nereis diversicolor*, *Harmothoe sarsi)*
Oligochaeta, Turbellaria, Nemertini, Insecta
Suspension feeders, selective praesediment feeders

First step of eutrophication:
Increase inbiomass, twofold or more (Bivalvia, Polychaeta)
Predominance of molluscs and snails
Decrease in crustaceae biomass
Disappearance of species (e. g. cockle *Parvicardium hauniense*, snail *Lymnea peregra*, crustaceans *Pontoporeia affinis*, *Bathyporeia pilosa)*
Filter feeders and deposit feeders

Second step of eutrophication:
Sometimes oxygen limitation; redox-discontinuity
Reduction of biomass to the former level
Predominance of *Nereis diversicolor*, *Corophium voluntator*, *Sphaeroma hookeri*, *Hydrobia ventrosa* and Oligochaetes
Other increasing species are *Cerastoderma glauca*, *Saduria entomon* and chironomid larvae (typical of polytrophic waters)

In step 1 and 2:
Very great temporal and spatial changes. Astonishing elasticity caused by euryplasticity and fast recolonization due to intact populations at the borders of eutrophic and polytrophic areas.

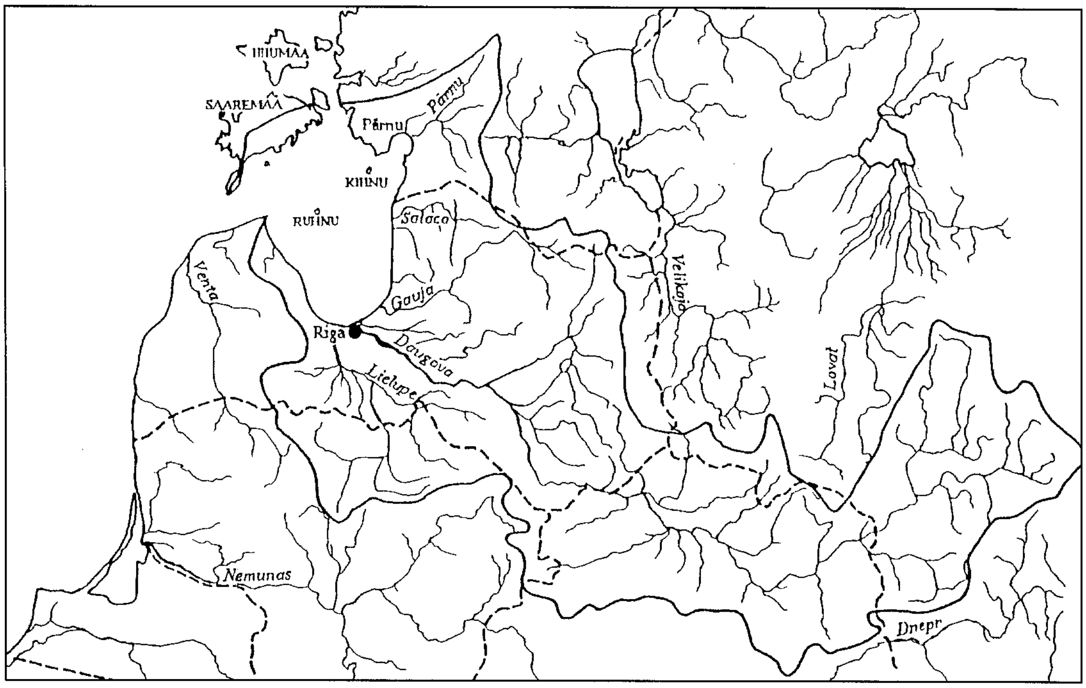

Fig. 9. Gulf of Riga and the catchment area (OJAVEER 1995).

with temperatures of around 0 °C of the water body. Reduced organismic activity and slower chemical processes are typical under such low temperature conditions.

In the past, increasing loads reduced the transparency (mainly in August) and the oxygen content of the deeper waters (Fig. 11). The biomass of the zoobenthos community increased. In the most seriously loaded region near Riga, the zoobenthic biomass is more or less the same as before, but the species number is lower. Bacterial counts have also increased in the Riga region, and the risk of *E. coli* infections has risen.

For the macrozoobenthos a two-stage development took place (Table 4).

The benthic macrofauna biomass increased and the dominance structure changed as eutrophication began. Later, the numbers of species and the biomasses decreased. Similar changes were observed in other Baltic estuaries as well, regardless of the species composition.

In spite of the high loads in the Gulf of Riga the system can be classified as mesotrophic/eutrophic. Low temperature restrict the turnover rate, but the greater depth and the high

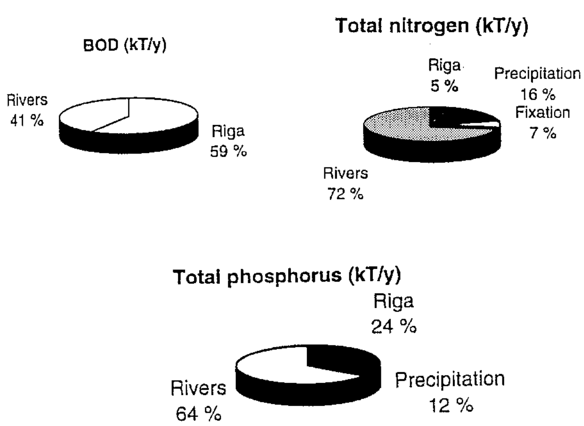

Fig. 10. Partial role of different sources and transportation ways in the loading of eutrophying substances into the Gulf of Riga (ANDRUSHAITS et al. 1995).

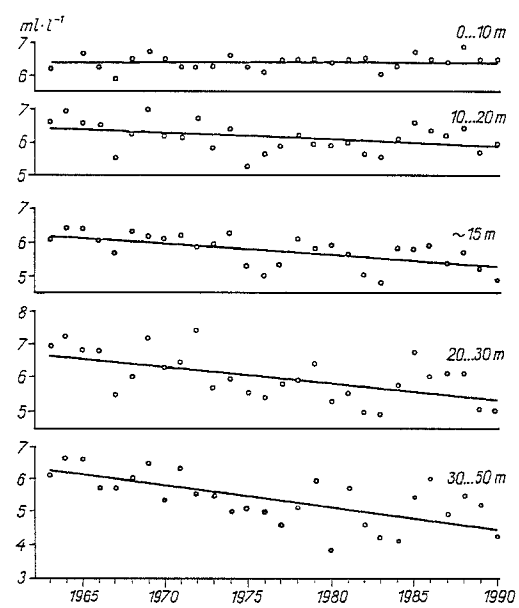

Fig 11. Long-term changes in oxygen concentration in the Gulf of Riga in summer (August). Calculated – 1963/70 from TGM-3M, 1963/70; 1971/93 from data LatFRi. (BERZINSH 1995).

exchange rate with the Baltic Sea compensate for this disadvantage. Finally, an unquantified part of the total load must be transported into the Baltic Proper, stressing its self-purification ability.

During the last 5 years river-borne loads have decreased dramatically, thereby changing the N/P-balance (see A. ANDRUSHAITIS 1996). The consequences for the ecosystem communities will of interest to all of us. The results of joint "Gulf of Riga Project" 1993/97 of the Nordic Council of Ministers will be of great interest.

General Conclusions

The results presented show that the three ecosystems considered have both common and specific reactions. Well coordinated monitoring programmes are needed to facilitate comparison. These should concentrate more on the service functions of the system. Normally, service functions are free of charge and not well measured. A healthy aquatic ecosystem has service functions that are many times greater than those of an eutrophic ecosystem. This makes healthy ecosystems robust and ensures their sustainable development. Recommendations for achieving the sustainability of Baltic estuary systems are summarized in Table 5.

The implementation of recommendations depends on political decisions. Scientists can offer several variants allowing a choice to find the best way to solve the main problems.

To solve the problems connected with restoration and sustainable development we need

- better knowledge of the self-regulation mechanisms in coastal ecosystems, e.g. in regard of its service and life support functions in different regions
- a generalized classification system based on a coordinated monitoring program
- a systems for assigning values of ecosystem benefits for the coastal zone. TURNER (1995) has shown what such a valuing system could look like (Fig. 12).

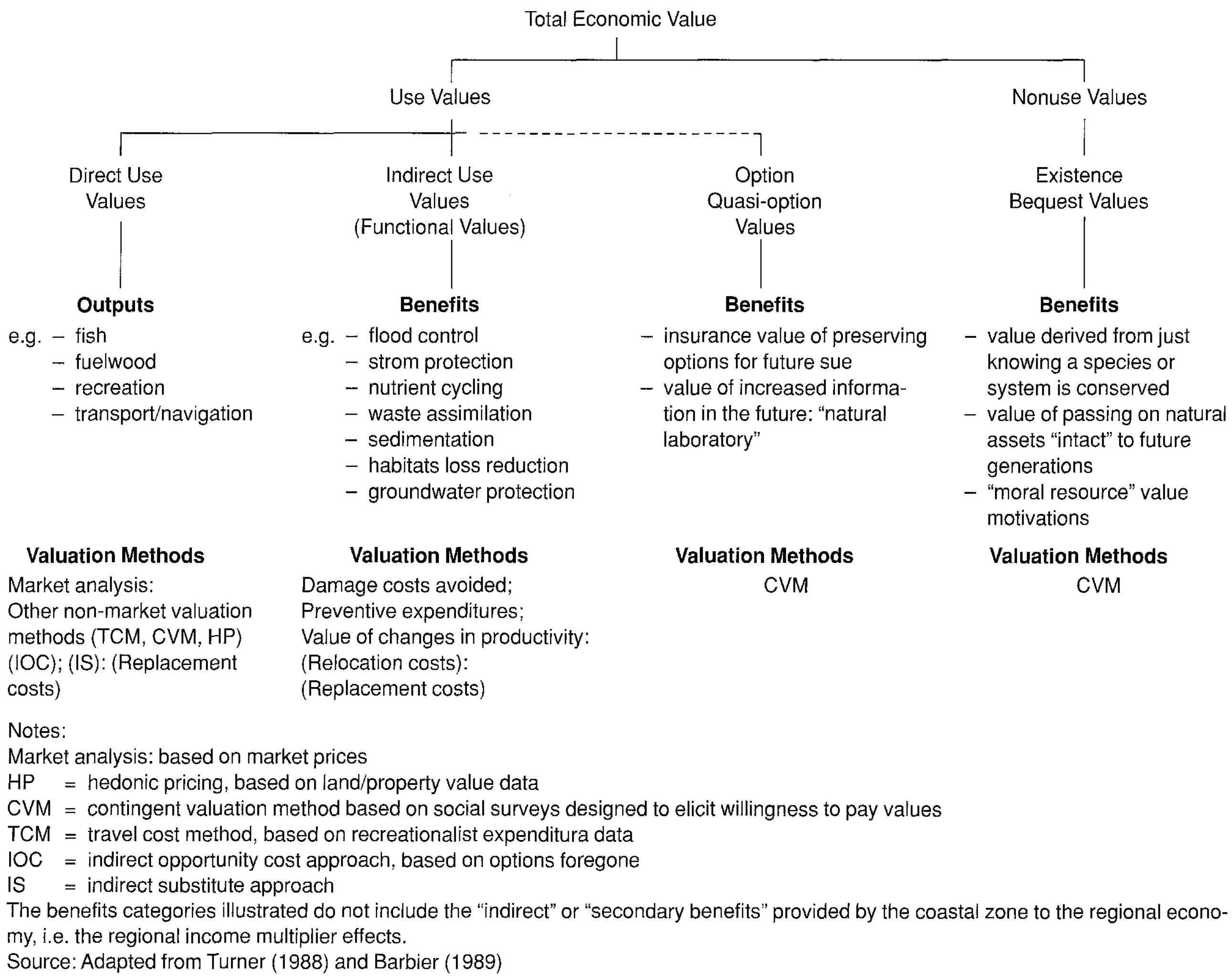

Fig. 12. Valuing coastal zone benefits (TURNER 1995).

Table 5. Recommendations.

– Ensuring the mutlivalent use of the estuaries to establish a mosaic of co-evolving socio-economical and ecological systems.
– Restoration of eutrophic aquatic ecosystems must include the restoration of the discharge (catchment) area.
– Building of 3-step sewage treatment plants for "hot spots".
– Creation of low-tech sewage treatment technology for small point sources in the entire drainage area.
– Adequate changes in the land use in the discharge area.
– Support the function of natural rather than anthropogenically disrupted capital, by feedbacks from the society, e.g. Recycling of waste into new resources; quantitative growth is to replace by qualitative improvements.
– Study of the self-regulation of ecosystems, especially with regard to life-support functions.
– Selection of areas for combined and comparative natural scientific and socio-economic studies.
– Development of more general monitoring and classification systems with more integrated assessments of coastal processes and systems.

Finally, we must consider the impact of the expected climatic change on the Baltic Sea and its estuaries. Increasing sea levels will enhance water exchange with the North Sea. A greater salt water inflow will be compensated for a greater outflow of low saline water. The higher salinity of the Baltic Sea will increase the distribution ranges of marine species and allow invasion by new marine species. On the other side, higher water temperatures will enhance the activity of microbial food webs. This might have several consequences at least in the estuary systems.

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